A. GÖSTA EKSPONG

SOME PROPERTIES OF THE SOFT COMPONENT OF COSMIC RADIATION

Neutral Mesons. — Bremsstrahlung

ALMQVIST & WIKSELLS BOKTRYCKERI AB
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SOME PROPERTIES OF THE SOFT COMPONENT OF COSMIC RADIATION

Neutral Mesons. — Bremsstrahlung

INAUGURAL DISSERTATION

BY

A. GÖSTA EKSPONG
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OF THE UNIVERSITY OF UPPSALA, TO BE PUBLICLY DISCUSSED
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Some Properties of the Soft Component of Cosmic Radiation

Neutral Mesons. Bremsstrahlung

The present dissertation is based on investigations published in the following three papers:

A. "Nuclear transmutations produced by cosmic-ray particles of great energy.—Part V. The neutral mesons." *Phil. Mag., 41*, 701, 1950 (in collaboration with J. E. Hooper and D. T. King).

B. "On multiple scattering measurements in nuclear research emulsions." *Arkiv f. Fysik, Bd 9*, Nr 5, 1954.

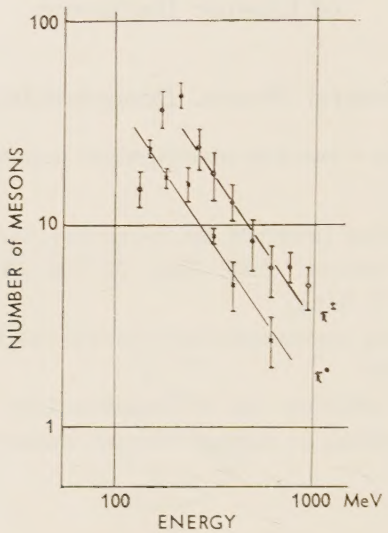
C. "Energy loss of fast electrons. An investigation into the absolute total cross-section for Bremsstrahlung in nuclear research emulsions." *Arkiv f. Fysik, Bd 9*, Nr 33, 1955.

Summary

The soft component of cosmic radiation is known to consist of electrons (negatively and positively charged) and photons of high energy. The number of these particles multiply in traversing matter, thereby giving rise to soft showers. The main mechanism involved is known to be this: photons create electron pairs and the latter reradiate photons in the Coulomb field of nuclei and electrons. A further possibility of a multiplication is the direct pair-creation by electrons, phenomenologically called tridents.

The source of the soft component remained obscure for some time. There were observations made prior to 1949 which strongly indicated that there exists a link between the soft and the hard component. At lower altitudes of the atmosphere the μ-mesons contribute by collision- and decay-electrons. At higher altitudes the connection between the hard and the soft component is now known to be due to the fact that both have a common origin in the high-energy collisions between particles of primary cosmic radiation and the nuclei of the atmosphere. The high-energy transmutations lead to the emission of charged π-mesons, which by their decay into μ-mesons result in the hard component, and the emission of neutral π-mesons, which by their decay into photons constitute the main source of the soft component. This view is supported by the observations described in (A). The spectrum of the γ-radiation

at the height of 70,000 ft. was found to have a characteristic form with a pronounced peak at about 76 MeV. The detailed form of the energy spectrum was found to be consistent with an interpretation as being due to neutral mesons (or more generally to moving sources) which emit an isotropic radiation of a unique energy (about 76 MeV) in their own frame of reference. The observed spread of energies ranging from a few MeV to more than 1000 MeV is in this interpretation due to the Doppler effect.



The distribution in energy of the neutral mesons emitted from nuclear disintegrations. Spectrum of neutral mesons, ×. Spectrum of charged mesons, as observed by CAMERINI *et al.*, ○. The ordinates have been chosen so as to display also the relative frequency of occurrence of neutral mesons as compared with charged mesons. Both scales are logarithmic.

Doubts may be raised as to the influence on the observed spectrum of the detector's position in the atmosphere relative to the neutral meson sources. According to the above review of the interpretation there seems, however, to be no need for a correction in this particular case. Methods were devised in (A) which allow a determination of the mass and the energy distribution of the neutral mesons. A further experiment yielded an upper limit of the life-time and gave a value of the frequency of occurrence of the neutral mesons. Some comments should be made about the mass of the neutral meson. The value found in (A) was based on the energies of the electrons, which are dependent on the scattering factor. Calibrations of nuclear emulsions have been carried out since then, to which references are given in (B). The new values show that the scattering factor employed in (A) was too high. A recalculation brings the mass to the value 230 m_e. In addition to the statistical error ($\pm$ 20 m_e) there should be added a possible systematic error of a few per cent connected with some uncertainty in the new scattering factor. There seems to

be no doubt that this particle is identical with the neutral meson produced artificially. The best mass value has been determined to $263.7 \pm 0.7\ m_e$, based on the capture of negative π-mesons in hydrogen (Padua Conference 1954). The distribution in energy of the neutral mesons is here reproduced with a correction of the energy scale (compare Fig. 7 of (A) where the charged meson points should be shifted to the right).

The two main elementary processes responsible for the development of soft showers are the pair-production and the Bremsstrahlung processes. Experiments on Bremsstrahlung in the high energy region are not plentiful. Recently, a number of experiments have been made with electrons from accelerators, to which references are given in (C). Yet, experiments on the total cross-section, ϕ_{rad}, are few. I have made an investigation into the energy losses of fast electrons traversing nuclear emulsions. The emphasis has been on electrons with energies in the region 100–1000 MeV. In (B) there is a description of the method by which the energy of the electrons have been determined, based on multiple scattering. Considerable care has been devoted to eliminating systematic errors in the microscope measurements. A semi-automatic recorder was constructed for registering the multiple scattering measurements. A new method is described in (C) to determine the total cross-section for Bremsstrahlung in nuclear emulsions—or the related quantity, the radiation length, if this is defined as $R = (N \phi_{\text{rad}})^{-1}$. The method consists in following the decrease of the average energy with the distance traversed. From the exponential degradation of energy, the radiation length may be determined in absolute measure. It was found that the limited thickness of the emulsions introduced a systematic error due to the tendency of electrons escaping from the emulsion. By employing the weight-factor correction worked out in (C) it was empirically found that the correction amounted to about -15 per cent in the present case. The measured energies were corrected for ionization and excitation energy losses. Observations of electron tracks in nuclear emulsions allow a fairly detailed investigation of "visible" interactions. Energy losses not attributable to such interactions are assumed to be due to radiation. No difficulties were encountered in following each track separately, thus removing one of the arguments raised against investigations based on the energy of electrons. The final samples of electrons yielded the following values of the radiation length: $R = 31 \pm 5$ mm for 100–250 MeV electrons, $R = 29 \pm 4$ mm for 250–1000 MeV electrons, and $R = 29 \pm 3$ mm for the total sample, viz. 100–1000 MeV electrons. The experimental uncertainty is given as the standard error, obtained from a least squares adjustment. These results are in good agreement with values derived from the Bethe-Heitler theory. In the case of the statistically best sample, viz. 100–1000 MeV electrons, the experimental result corresponds to a total cross-section 4 per cent (± 10 per cent) higher than that derived from theory. In the nuclear emulsion, Ilford G5 in the present case, the Ag and Br atoms contribute about 95 per cent to the total cross-section. The experiment may therefore be considered equivalent to an investigation of the Bremsstrahlung in a material with $Z \sim 40$.

ACKNOWLEDGEMENTS

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Contents

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[1] Previous papers have been published by the present author under the name of Carlson.

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B. GÖSTA EKSPONG: On multiple scattering measurements in nuclear research emulsions. *Arkiv f. Fysik, Bd 9*, Nr 5, 1954.

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